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APPLICATION NUMBER: *60/403,874*
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PTO/SB/16 (8/96)
Approved for use through 01/31/98. OMB 0651-0037
Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE

Attorney Docket No. 1340.P088Z Type a plus sign (+) inside this box [+]

PROVISIONAL APPLICATION FOR PATENT COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53 (c).

INVENTOR(s)/APPLICANT(s)

LAST NAME	FIRST NAME	MIDDLE NAME/ INITIAL	RESIDENCE (CITY AND EITHER STATE OR FOREIGN COUNTRY)
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TITLE OF THE INVENTION (280 characters max)

VECTORING TECHNIQUES FOR MULTI-LINE COMMUNICATION SYSTEMS

CORRESPONDENCE ADDRESS (including country if not United States)

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ENCLOSED APPLICATION PARTS (check all that apply)

X Specification Number of Pages 16 ____ Small Entity Statement

X Drawing(s) Number of Sheets 13 ____ Other (specify)

METHOD OF PAYMENT OF FILING FEES FOR THIS PROVISIONAL APPLICATION FOR PATENT (check one)

X A check or money order is enclosed to cover the filing fees

X The Commissioner is hereby authorized to charge filing fees and credit Deposit Account No. 02-2666

Filing Fee Amount ($) $160.00

This invention was made by an agency of the United States Government or under contract with an agency of the United States Government..

X No

____ Yes, the name of the U.S. Government Agency and the Government Contract Number are: ____

Respectfully submitted,

SIGNATURE [signature] DATE 8/16/02

TYPED or PRINTED NAME: Daniel E. Ovanezian REGISTRATION NO. 41,236
(if appropriate)

____ Additional inventors are being named on separately numbered sheets attached hereto

USE ONLY FOR FILING A PROVISIONAL APPLICATION FOR PATENT

Address to: Box Provisional Application, Assistant Commissioner for Patents, Washington, D. C. 20231

PTO/SB/17(09/00)
Approved for use through 10/31/2002. OMB 0651-0032
Patent and Trademark Office: U.S. DEPARTMENT OF COMMERCE

FEE TRANSMITTAL FOR FY 2002

TOTAL AMOUNT OF PAYMENT ($) 160.00

Complete if Known:
Application No. Not yet assigned
Filing Date Herewith
First Named Inventor Michail Tsatsanis
Group Art Unit Not yet assigned
Examiner Name Not yet assigned
Attorney Docket No. 1340.P088Z

METHOD OF PAYMENT (check one)

1. [X] **The Commissioner is hereby authorized to charge indicated fees and credit any over payments to:**

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[ ] **Applicant claims small entity status. See 37 CFR 1.27**

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FEE CALCULATION

1. BASIC FILING FEE

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description	Fee Paid
101	740	201	370	Utility application filing fee	
106	330	206	165	Design application filing fee	
107	510	207	255	Plant filing fee	
108	740	208	370	Reissue filing fee	
114	160	214	80	Provisional application filing fee	160.00

SUBTOTAL (1) $ 160.00

2. EXTRA CLAIM FEES

			Extra Claims		Fee from below		Fee Paid
Total Claims	______	– 20** =	______	X	______	=	______
Independent Claims	______	– 3** =	______	X	______	=	______
Multiple Dependent					______	=	______

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Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description
103	18	203	9	Claims in excess of 20
102	84	202	42	Independent claims in excess of 3
104	280	204	140	Multiple dependent claim, if not paid
109	84	209	42	**Reissue independent claims over original patent
110	18	210	9	**Reissue claims in excess of 20 and over original patent

SUBTOTAL (2) $______

FEE CALCULATION (continued)

3. ADDITIONAL FEES

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description	Fee Paid
105	130	205	65	Surcharge - late filing fee or oath	
127	50	227	25	Surcharge - late provisional filing fee or cover sheet	
139	130	139	130	Non-English specification	
147	2,520	147	2,520	For filing a request for ex parte reexamination	
099	8,800	099	8,800	Request for inter parties reexamination	
112	920*	112	920*	Requesting publication of SIR prior to Examiner action	
113	1,840*	113	1,840*	Requesting publication of SIR after Examiner action	
115	110	215	55	Extension for reply within first month	
116	400	216	200	Extension for reply within second month	
117	920	217	460	Extension for reply within third month	
118	1,440	218	720	Extension for reply within fourth month	
128	1,960	228	980	Extension for reply within fifth month	
119	320	219	160	Notice of Appeal	
120	320	220	160	Filing a brief in support of an appeal	
121	280	221	140	Request for oral hearing	
138	1,510	138	1,510	Petition to institute a public use proceeding	
140	110	240	55	Petition to revive – unavoidable	
141	1,280	241	640	Petition to revive - unintentional	
142	1,280	242	640	Utility issue fee (or reissue)	
143	460	243	230	Design issue fee	
144	620	244	310	Plant issue fee	
122	130	122	130	Petitions to the Commissioner	
123	50	123	50	Processing fee under 37 CFR 1.17(q)	
126	180	126	180	Submission of Information Disclosure Stmt	
581	40	581	40	Recording each patent assignment per property (times number of properties)	
146	740	246	370	For filing a submission after final rejection (see 37 CFR 1.129(a))	
148	110	248	55	Statutory Disclaimer	
149	740	249	370	For each additional invention to be examined (see 37 CFR 1.129(b))	
179	740	279	370	Request for Continued Examination (RCE)	
169	900	169	900	Request for expedited examination of a design application	
195	300	195	300	Publication fee for early, voluntary, or normal pub.	
196	300	196	300	Publication fee for republication	
194	130	194	130	Request for voluntary publication or republication	
098	130	098	130	Processing fee under 37 CFR 1.17(i) (except provisionals)	
091	1,280	091	1,280	Acceptance of unintentionally delayed claim for priority	

Other fee (specify) ____________________

Other fee (specify) ____________________

SUBTOTAL (3) $________

*Reduced by Basic Filing Fee Paid

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Signature: [signature] Date: 8/16/02

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UNITED STATES PROVISIONAL PATENT APPLICATION

FOR

VECTORING TECHNIQUES FOR MULTI-LINE COMMUNICATION SYSTEMS

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VECTORING TECHNIQUES FOR MULTI-LINE COMMUNICATION SYSTEMS

FIELD OF THE INVENTION

[0001] The present invention relates generally to communication systems and, in particular to, vectoring techniques for multiple line communication systems.

BACKGROUND OF THE INVENTION

[0002] The stated goals of the 10MDSL project call for 10 Mbps service over CSA range. This level of performance exceeds the capacity of a single copper pair of that length (9,000ft 26AWG). Therefore, the objectives of the standard can only be met by bonding together multiple copper pairs.

[0003] The use of multiple pairs to deliver services over copper has a long history. Examples include two pair systems like HDSL and inverse multiplexers of several pairs (usually at the ATM layer). Recently, there has been a revived interest in multipair systems in an effort to fully exploit the copper infrastructure. The 10MDSL standard considers bonding of up to 4-5 pairs. The EFM group also considers scalable multiline systems for long reach Ethernet services. Finally, solutions have been proposed for bonding a full 25 pair binder together.

[0004] In the past, the focus of multipair bonding has been at the digital layer (e.g., inverse multiplexers). Some current activities are also focused on

digital multiplexing solutions (e.g., the ITU G.bond standardization effort). In contrast, the scope of the 10MDSL project allows for physical layer recommendations and hence provides the opportunity for studying physical layer bonding (or *vectoring*). Vectoring refers to technologies that allow for coordinated transmission across multiple pairs so that communication takes place through a "vector" of waveforms. Typically, vectored transceivers can be implemented through Multi-Input-Multi-Output (MIMO) signal processing techniques. Various aspects of MIMO technology have been proven in the wireless area (in the context of multiple transmit and receive antenna systems) and have been pursued under the IEEE 802.16 working group for fixed wireless services.

[0005] The degree to which one should depart from the traditional Single-Input-Single-Output (SISO) transceiver paradigm in standardizing a multipair system is an interesting question of cost and benefit, of complexity and performance. In order to make the appropriate tradeoffs, one should consider an array of related transceiver design questions:

- What is the fundamental MIMO architecture that is suited to the MIMO copper environment?
- Can existing single carrier and/or multi carrier standards be relatively easily adapted to their MIMO versions?
- What is the associated complexity?

- What are the performance gains and are they worth the effort?

The objective of this contribution is to assist in addressing these questions, and to emphasize the performance gains that are possible through vectored transmission. It is our hope that this contribution will generate interest among the community to further investigate MIMO techniques and provide more studies in this area.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] The present invention is illustrated by way of example and not limitation in the figures of the accompanying drawings, in which like references indicate similar elements and in which:

[0007] Figure 1 is an illustrated embodiment of in-domain and out-of-domain crosstalk.

[0008] Figure 2 is an illustrated embodiment of an in-domain NEXT cancellation architecture.

[0009] Figure 3 is an illustrated embodiment of a generic SISO transceiver architecture.

[0010] Figure 4 is an illustrated embodiment of a generic MIMO transceiver architecture.

[0011] Figure 5 is an illustrated embodiment of a FEXT cancellation example.

[0012] Figure 6 is an illustrated embodiment of a simple example of out-of-domain crosstalk mitigation.

[0013] Figure 7 is an illustrated embodiment of upstream MIMO rates of 4 in-domain lines (26AWG) with Annex J spectral mask.

[0014] Figure 8 is an illustrated embodiment of upstream MIMO rates of 3 in-domain lines (26AWG) with Annex J spectral mask.

[0015] Figure 9 is an illustrated embodiment of upstream MIMO rates of 4 in-domain lines (26AWG) with SHDSL spectral mask.

[0016] Figure 10 is an illustrated embodiment of upstream MIMO rates of 3 in-domain lines (26AWG) with SHDSL spectral mask.

[0017] Figure 11 is an illustrated embodiment of upstream MIMO rates of 4 in-domain lines (26AWG) with SHDSL spectral mask.

[0018] Figure 12 is an illustrated embodiment of upstream MIMO rates of 3 in-domain lines (26AWG) with SHDSL spectral mask.

[0019] Figure 13 is an illustrated embodiment of a comparison of theoretical and laboratory results (4 lines, 9Kft, 26AWG).

DETAILED DESCRIPTION

[0020] Basic Vector MIMO Architecture.

[0021] In order to identify the basic required blocks in a multipair transceiver, we should start with a brief overview of the environment that the transceiver will operate in and of the impairments it will have to contend with. Figure 1 shows a binder with a number of pairs belonging to a multipair system called in-domain pairs (blue/light gray), as well as a number of other active pairs belonging to other services and called out-of-domain pairs (red/dark grey).

[0022] It will be useful to distinguish between crosstalk generated from in-domain lines to that generated from out-of-domain lines, as the approach to mitigate it differs in each case. Since the transceiver has access to the data transmitted on the in-domain interfering lines, it is not hard to imagine that in-domain NEXT crosstalk can be cancelled in a manner similar to the way echo is cancelled in symmetric modems. Figure 2 shows a block diagram with a MIMO echo and NEXT canceller. This structure is useful if the upstream and downstream spectral masks overlap and there is substantial echo and in-domain NEXT present. In the case of an FDM spectral mask, the echo/NEXT cancellation block may not be necessary.

[0023] It should be pointed out that the in-domain crosstalk in Figure 1 is not necessarily the dominating source of crosstalk. Since the coupling strength of the NEXT co-channels varies among copper pairs, it is conceivable that out-of-domain crosstalk may in many cases dominate. Further, in-domain and out-of-

domain FEXT may be present in shorter loops. Hence, if the multiline transceiver does not take active steps in mitigating FEXT and out-of-domain crosstalk, it is questionable if in-domain cancellation alone will provide significant benefits. An exception to that argument can be made when the multiline system has full control of the entire binder so that no out-of-domain disturbers exist in the binder.

[0024] In order to understand the basic required architecture for signaling across a MIMO loop plant channel and in the presence of a vectored noise process, let us start with a review of the SISO transceiver architecture. Figure 3 shows a generic SISO architecture that applies to single carrier as well as multi carrier architectures. In both cases, the modems employ transmitter and receiver filtering and signal processing in order to (i) combat the channel induced intersymbol interference and (ii) optimally adjust to the noise characteristics. Single carrier modems typically implement this architecture through time domain digital filters, while multi carrier modems through time and frequency domain filters in conjunction with FFT and IFFT operations.

[0025] In the case of a multiline transceiver, this architecture should be extended as shown in Figure 4. The difference is that the constellation encoder should encode bits in a "super-constellation" or vector constellation that spans multiple lines and that the SISO Tx and Rx filters should now be MIMO filters that filter signals from all lines in a vectored or coordinated way.

[0026] At first, Figure 4 appears to suggest that a completely new PHY layer with a different modulation scheme is needed in order to implement vectored transmission. In turns out however, that the MIMO processing aspect of the transceiver can be sufficiently separated from the modulation scheme in a way that existing PHYs can be extended to the vectored case with only modest modifications. For single carrier modems, a MIMO version of the Tomlinson-Harashima precoder should be accommodated, while for DMT modems MIMO versions of the time and frequency equalizers would be needed. In both cases the basic structure of the associated filters could be standardized with explicit hooks into the existing PHY processing blocks so that interoperability of vector transmission equipment can be guaranteed.

[0027] <u>Benefits of Vectored Transmission</u>.

[0028] The natural question that arises from the discussion in the previous section is whether vector transmission improves system performance so that the architectural changes required are warranted. The quantitative performance results presented in the next section support a positive answer to that question. Before presenting performance graphs however, let us qualitatively discuss the nature of the performance benefits possible with vectored transmission.

[0029] Figure 5 illustrates the benefits of vectored transmission in a FEXT cancellation example. In this case the vectored transmitted signals undergo a FEXT induced distortion in the binder described by the MIMO channel response $\mathbf{H}_{fext}$. The figure depicts how a vector receiver could potentially implement a

MIMO equalizer, which could invert the FEXT channel and mitigate the FEXT crosstalk interference.

[0030] Figure 6 describes a simplified example, which illustrates the principle of out-of-domain crosstalk mitigation. Consider two lines that are subjected to a single out-of-domain disturber (denoted by x in the figure). In a SISO architecture both of those lines will have to operate under this interference as shown in the top part of the figure (in this simple example we assume that the two in-domain lines do not interfere with each other). A vectored transceiver can process the two signals by adding and subtracting them at the transmitter and then again at the receiver (see bottom part of Figure 6). This operation results in canceling the out-of-domain noise in one of the two lines, while recovering the original signals. Real world crosstalk conditions are clearly more complicated than this idealized example, but the message of this illustration is that there exist optimal vector transmission techniques that can mitigate both FEXT and NEXT crosstalk from in and out-of-domain disturbers. Also, in a realistic design one should be more careful with the appropriate scaling of the signals at the transmitter and the receiver so that transmit power limits are observed.

[0031] <u>Performance Examples</u>.

[0032] The objective of this section is to provide some concrete quantitative results on the performance that should be expected from a vectored system in the context of 10MDSL. A difficulty associated with that task is that different implementations of a vectored architecture (for example due to

different line codes) could lead to somewhat different performance. It would be premature at this point to pick a very specific MIMO implementation given the state of the discussions within the 10MDSL project. In order to address that difficulty we present results of the MIMO capacity of a vectored system, and give an indication of what is possible independent of the implementation. We couple that with some laboratory results from a hardware prototype system we have developed at Voyan to address questions of feasibility and implementability.

[0033] The results presented next are calculated based on the MIMO capacity formula

$$C = \frac{1}{2}\int \log_2 \det(I + R^{-1/2} H S_{xx} H' R^{-1/2}) df$$

where S_{xx} is the transmitted signal spectral matrix, H is the MIMO loop plant channel and R is the interference plus noise matrix PSD. A gap to capacity corresponding to a BER=1e-7 is used with 6 dB of margin and 5.1 dB of coding gain as is common in other DSL systems. The impairment corresponding to each disturber is calculated using the Telcordia published co-channel transfer functions and picking random co-channels for the different disturbers. While several aggregate crosstalk models have been proposed in the past, they are not valid in representing interference in multiline models and were therefore of limited use in this case. Finally a noise floor of –140 dBm/Hz was added.

[0034] We begin our presentation by considering a system that implements the Annex J spectral mask. Figure 7 depicts the achievable data rates

for a 4 line system in a binder full of services mostly of the same type. Results for 0, 1, 5 and 12 SHDSL disturbers are shown while the rest of the binder is filled up with self-disturbers. Figure 8 shows similar results for a 3 line system. Those figures indicate that the 10 Mbps objective may be possible over 9,000ft with a four pair system. Only upstream rates are shown because for a symmetric application under the Annex J mask the upstream presents the bottleneck of the system.

[0035] In order to investigate what is possible with a more liberal spectral mask, Figure 9 depicts similar rate reach results for a 4 line system using the SHDSL mask. An extra line is added to that graph showing the performance when the binder is full of SHDSL disturbers. In the other cases, there are 0, 1, 5 and 12 SHDSL disturbers as well as in-domain interference. Figure 10 shows similar results for a 3 pair system.

[0036] Figure 11 and Figure 12 show the performance of a 4 and 3 line system respectively under disturber scenarios. Various disturber scenarios are proposed based on loop surveys, corresponding to a certain percentage coverage of the overall network in North America. The crosstalk interference calculation was again based on the published Telcordia co-channel measurements. Adjacent binder interference was omitted due to lack of adjacent binder multipair co-channel models or measurements. Notice that even for the 99% coverage case, the 4 line vectored architecture has a capacity that exceeds the 10Mbps objective.

Also the achievable data rates are well beyond the "desired" loop reach objectives.

[0037] The last figure in this section compares the previous theoretical results with data rates achieved in the lab using our hardware prototype system for a few select cases. Our implementation is based on a MIMO extension of the DMT architecture. Our system can have programmable spectral masks allowing us to provide results for both Annex J and SHDSL masks. In the lab experiment we run the cases of 5 and 12 disturbers at 9,000ft 26AWG. We approximated the spectral characteristics of SHDSL disturbers with SDSL ones running at 1Mbps (we did not have 12 SHDSL modems in the lab). Notice that data rates fairly close to the capacity are achievable in a real hardware implementation.

[0038] A comparison with SISO techniques may be made, where the capacity of SHDSL modems operating with no coordination or crosstalk mitigation is calculated at about 1.5 Mbps per line for the conditions of our experiments.

[0039] 10MDSL is perhaps the first DSL standard to study the use of multiple copper pairs as an integral part of the PHY and not as an afterthought. It faces the challenge of designing an appropriate vectored PHY for the MIMO channel conditions, yet doing so by small modifications of existing PHYs and line codes. The current contribution provides encouraging results both on the performance and implementability of vector architectures. MIMO solutions can clearly satisfy both the minimal and "desired" 10MDSL reach objectives. Further,

they can extend the reach of 10MDSL to full CSA range enabling its wide deployment.

CLAIMS

What is claimed is:

1. A method, comprising:

providing multiple 10MDSL lines; and

programming spectral masks.

ABSTRACT

Vectoring techniques for multiline 10MDSL systems, basic MIMO architectures, and the benefits of coordinated transmission across multiple lines are described. Theoretical and laboratory results on the performance of vectored MIMO transmission for 3 and 4 line systems are described.

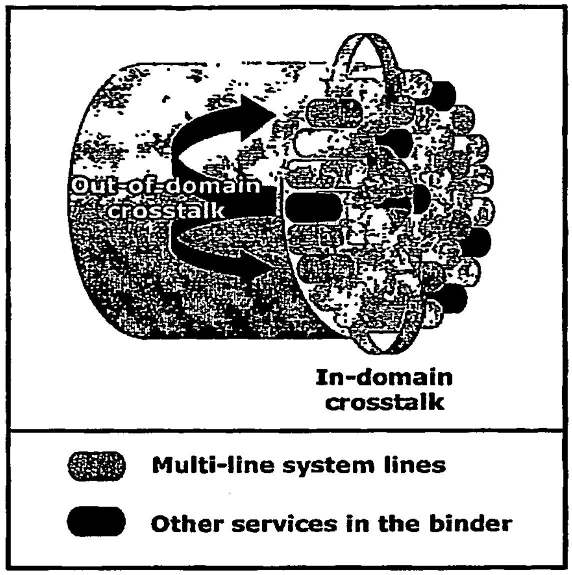

Figure 1: In-domain and out-of-domain crosstalk

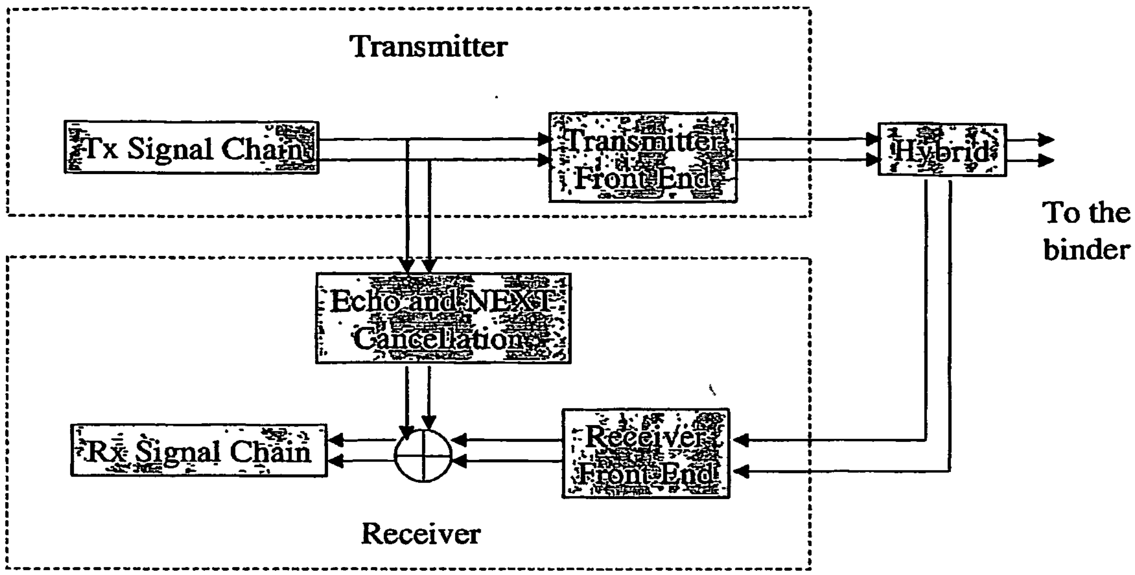

Figure 2: In-domain NEXT cancellation architecture

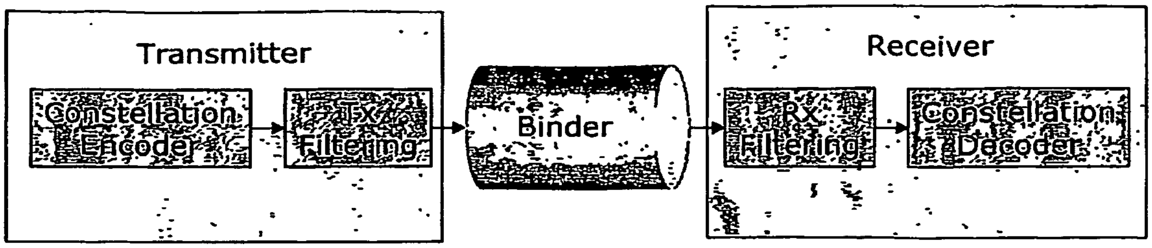

Figure 3: Generic SISO transceiver architecture

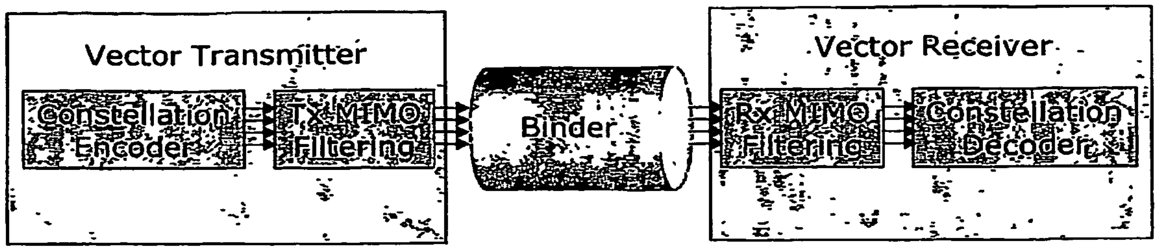

Figure 4: Generic MIMO transceiver architecture

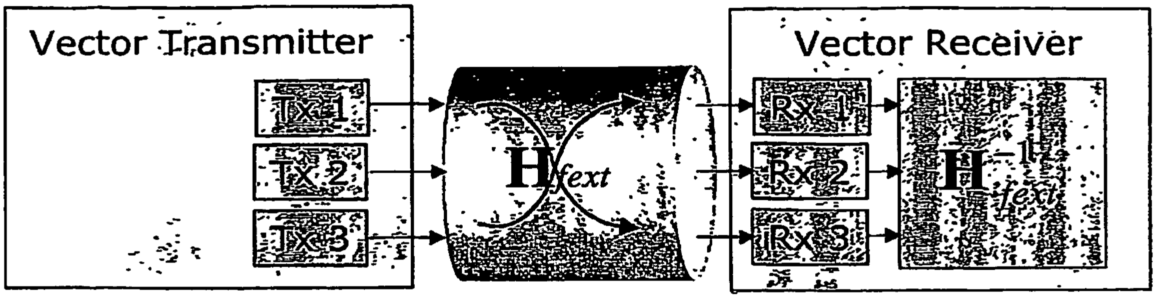

Figure 5: FEXT cancellation example

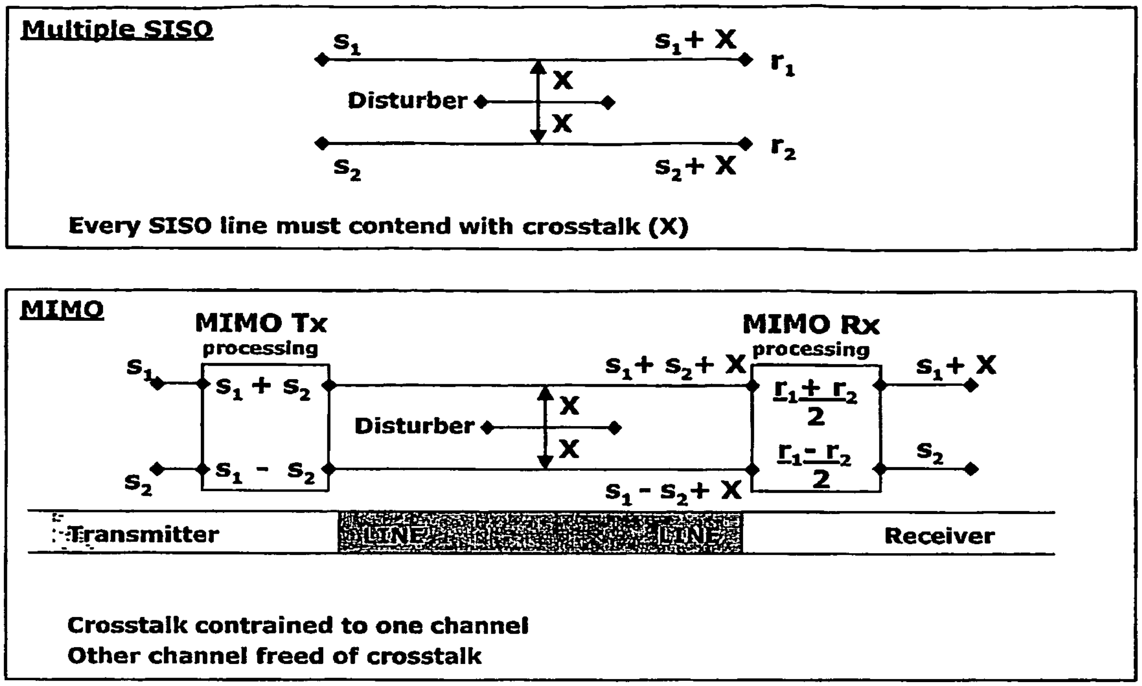

Figure 6: Simple example of out-of-domain crosstalk mitigation

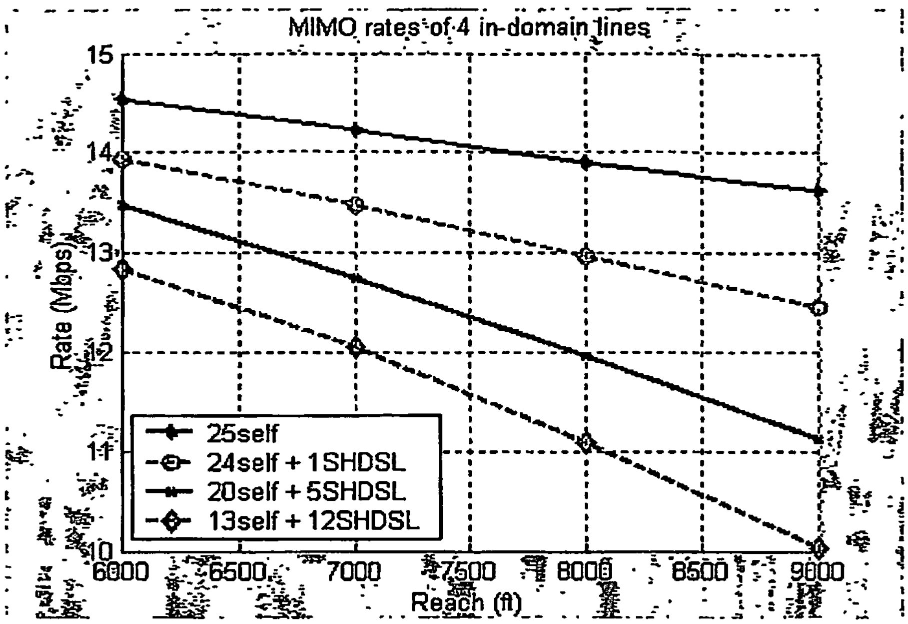

Figure 7: Upstream MIMO rates of 4 in-domain lines (26AWG) with Annex J spectral mask

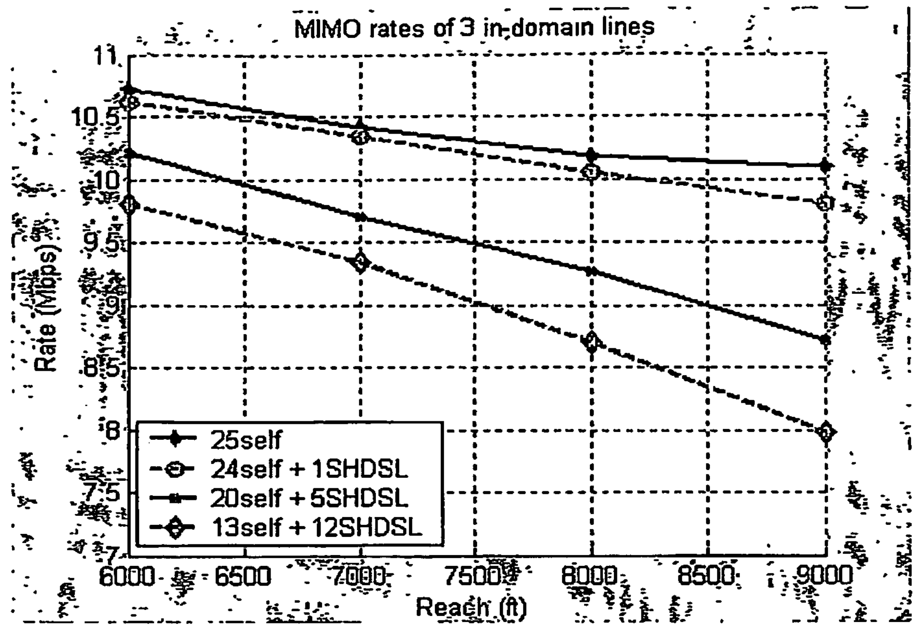

Figure 8: Upstream MIMO rates of 3 in-domain lines (26AWG) with Annex J spectral mask

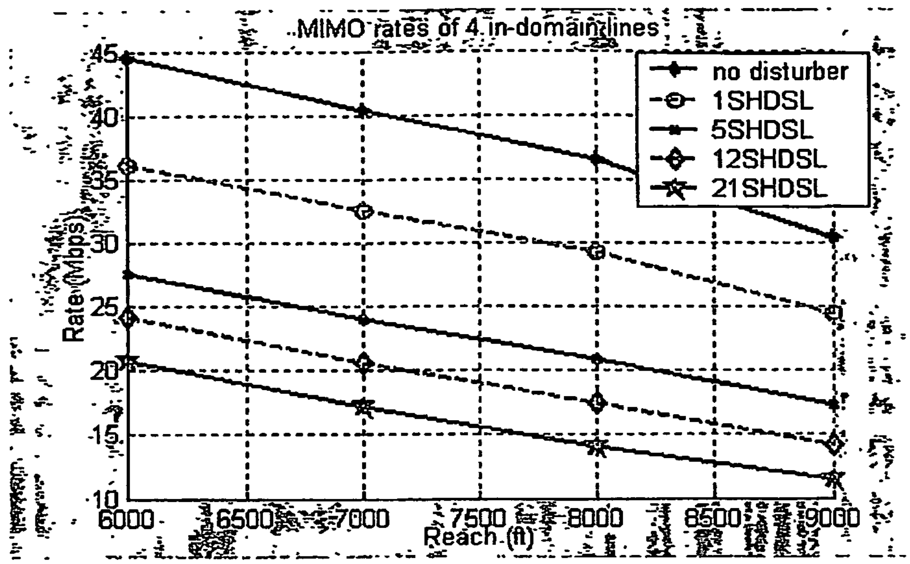

Figure 9: Upstream MIMO rates of 4 in-domain lines (26AWG) with SHDSL spectral mask

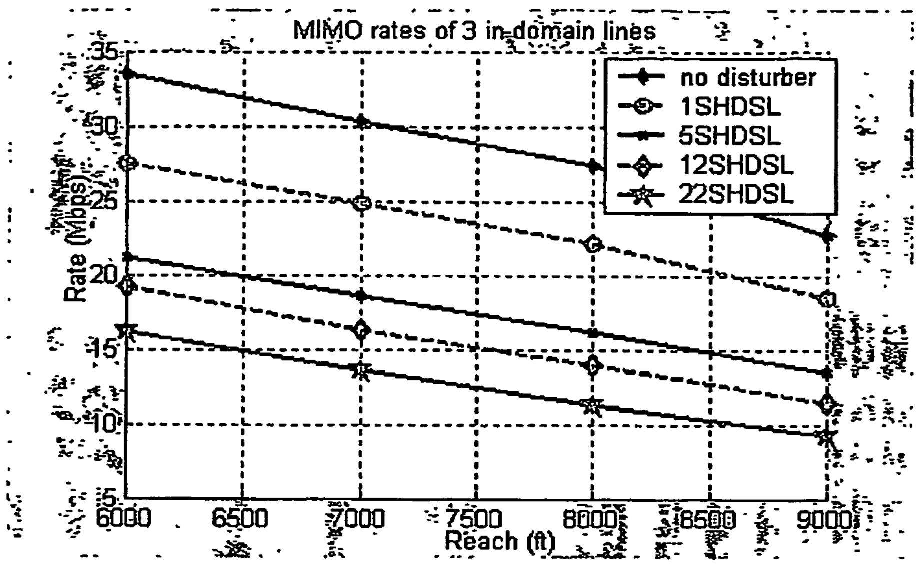

Figure 10: Upstream MIMO rates of 3 in-domain lines (26AWG) with SHDSL spectral mask

[redacted]

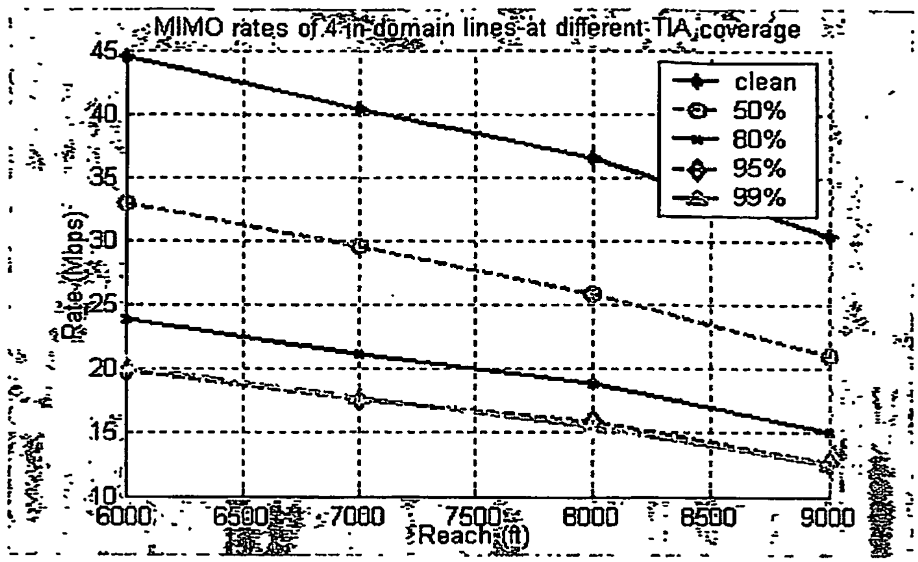

Figure 11: Upstream MIMO rates of 4 in-domain lines (26AWG) with SHDSL spectral mask

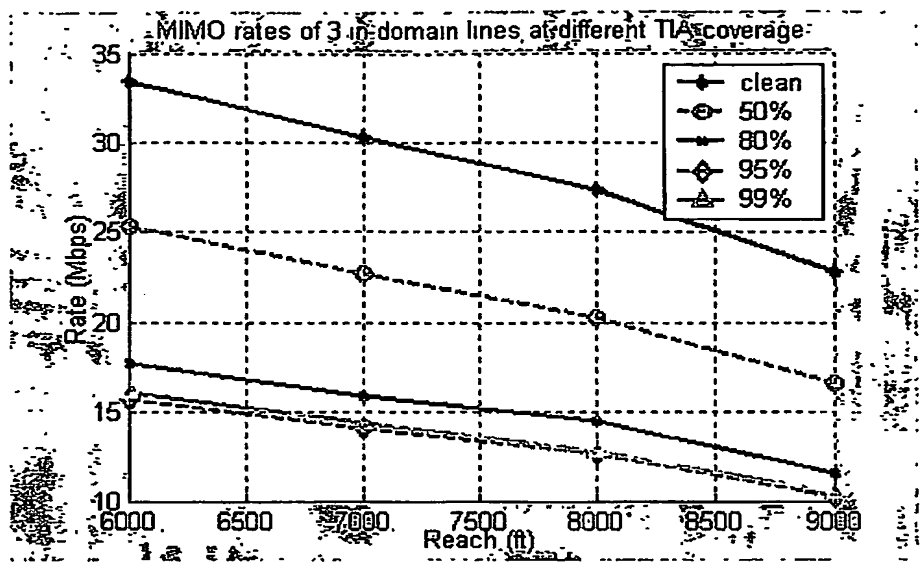

Figure 12: Upstream MIMO rates of 3 in-domain lines (26AWG) with SHDSL spectral mask

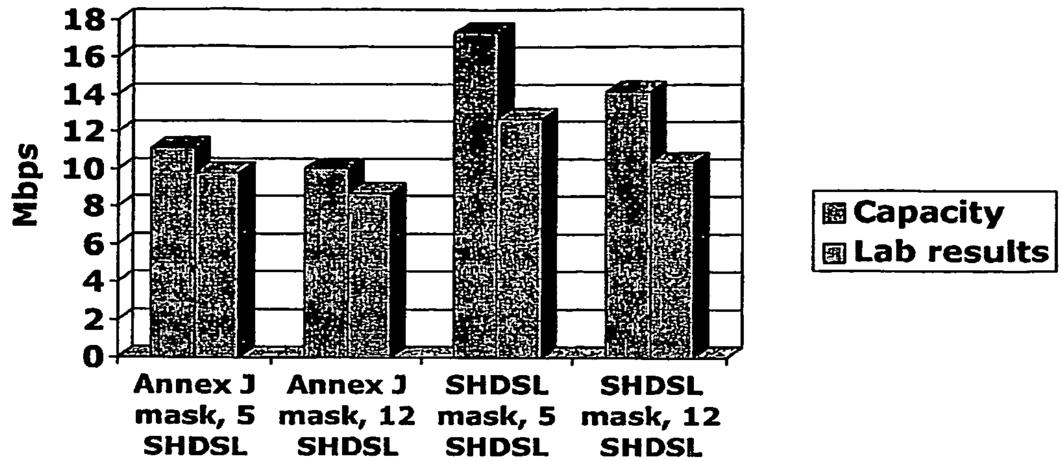

Figure 13: Comparison of theoretical and laboratory results (4 lines, 9Kft, 26AWG)